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DISCHARGE COEFFICIENTS FOR SPILLWAYS AT TVA DAMS

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HYDRAULICS DIVISION

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DISCHARGE COEFFICIENTS FOR SPILLWAYS AT TVA DAMS

Kenneth W. Kirkpatrick,[1] A.M. ASCE

SYNOPSIS

Spillway ratings derived from model studies have been used in the preparation of spillway rating tables for the Tennessee Valley Authority's dams. As a result of these studies, discharge coefficients for eleven of the Tennessee Valley Authority dams are given in this paper. Coefficients for both submerged and free discharge conditions are presented for discharges over standard spillway crests, irregular spillway crests, and a vertical lift spillway gate. Discharge coefficients for Tainter gates placed on curved spillway crests are also given for various gate openings under free discharge conditions. Data on the effect of model scale on the discharge coefficient and the effect of closing adjacent spillway bays and gates are also presented. The coefficient relationships are presented in a form that may be used by designers as a guide in making determinations of the discharges for future spillways.

INTRODUCTION

The Tennessee Valley Authority (TVA) operates a system of nine dams on the Tennessee River and twenty-three on the tributary rivers. The successful operation of such a system requires accurate discharge ratings for each structure. Since water is seldom available to make complete ratings for most spillways from measurements conducted on the prototype structure but can be determined from scale model tests, the necessary ratings for TVA's spillways have been obtained by this means. Model studies have been made at TVA's Hydraulic Laboratory at Norris, Tennessee, on nine different spillway crest shapes equipped with three types of control gates.

Seven of the nine crests were curved sections which more or less approximated the shape of the lower nappe of a sharp-crested weir. The other two crests were flat. The two flat-crested weirs and one of the curved crests were equipped with double-leaf vertical lift gates. Five of the curved crests were equipped with Tainter gates and the other with vertical lift gates.

Data Presented

Data are presented for the following conditions:

1) Free, ungated flow through a series of spillway bays.
2) Submerged, ungated flow through a series of spillway bays.
3) Free, ungated flow through a series of spillway bays, with adjacent bays fully open or closed.
4) Free flow over a vertical lift gate.
5) Submerged flow over a vertical lift gate.
6) Flow under a series of Tainter gates set with equal openings.
7) Flow under a series of Tainter gates with adjacent gates closed.

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Data are also presented to show the effect of model scale for the condition of free, ungated flow through a series of spillway bays.

General Model Setup

The models were tested in flumes either 3.5 feet or 8 feet wide. Models installed in the smaller flume usually consisted of a reproduction of three of the prototype spillway bays. In the larger flume five or six spillway bays were reproduced. Each of these flumes was provided with glass panels for observation purposes. The models placed in the larger flume were constructed at scale ratios of from 1:28.72 to 1:50 with a ratio of about 1:35 most usually used. Those tested in the smaller flume were built at scale ratios of 1:50, 1:100, and 1:200.

The models were usually provided with concrete crests and concrete piers to insure dimensional stability. Half piers were constructed on the ends of the model. One side of the model was placed against the glass side of the flume and the other against a false wall if the model did not completely fill the flume. The river bed upstream and downstream from the model was reproduced at the elevation of the prototype river bed. Suitable baffling was provided to obtain a uniform distribution of flow in the spillway approach channel. The tailwater level was controlled at the end of the flumes with slat gates. Model discharges were obtained from readings of a carefully calibrated diaphragm orifice located in the water supply line.

Headwater heights were measured at two piezometers located approximately 5 and 8 times the design head upstream from the spillway crest. Tailwater heights were obtained at two piezometers located approximately 9 and 12 times the design head downstream from the spillway crest or in all cases sufficiently far enough downstream to eliminate the effect of the spillway apron.

In most studies the headwater and tailwater levels were determined by hook gages reading to 0.001 foot. For the 1:200 scale model the heads were measured with a micrometer point gage reading to 0.0001 foot.

Discharge Equations

The model data have been reduced by the use of two commonly accepted discharge equations. For both free and submerged flow over a spillway crest the equation

$$Q = CLH^{3/2} \tag{1}$$

was used. Q is the discharge in cubic feet per second. C is the coefficient of discharge determined from the model tests, L is the length of the crest, and H is the total head as shown in Figure 1(a). Use was made of the same equation in the reduction of the data for free and submerged flows over a vertical gate with D, H, d, and P, Figure 1(a), being measured from the top of the gate.

For flow under a gate the equation

$$Q = CL\left[H^{3/2} - (D_1 + h)^{3/2}\right] \tag{2}$$

which is the equation for a rectangular orifice under low head was used. D_1 is the depth of water to the bottom of the gate as defined in Figure 1(b) and h is the approach velocity head.

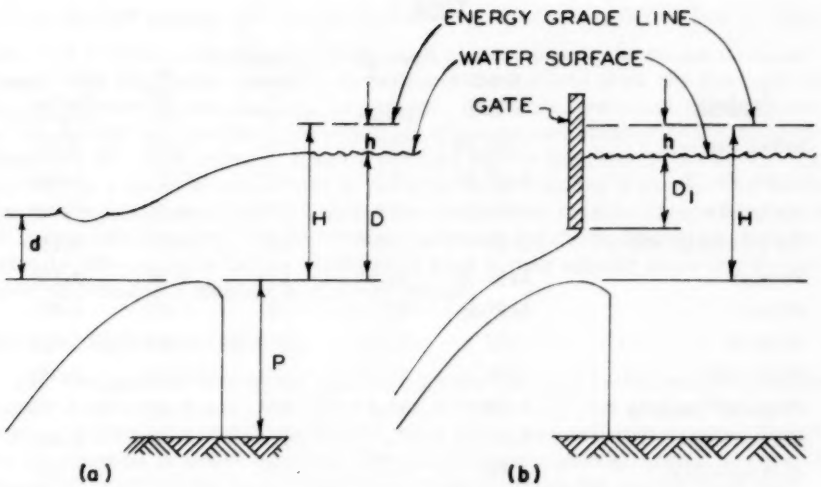

FIGURE 1

Free Discharge Coefficients for Flow over Spillway Crests

It is common practice for engineers to design spillway crests to approximate closely the shape of the lower portion of a jet issuing from a sharp-crested weir, and this type of crest is designated a standard crest.(1) Since the shape of the jet changes with the head on the weir, some particular head must be used for each design. This head for which a particular crest is designed is designated the design head. At this head, pressures near atmospheric are developed at the spillway surface. At smaller heads the pressures are greater than atmospheric. Seven of the nine TVA crests for which data are available approximate standard crests in shape while the other two crests, which are flat, do not.

Figures 2, 3, and 4 present the coefficient data obtained on these crests and show the basic details and dimensions of each crest. Table 1 gives pertinent design data concerning each together with the scale to which each was modeled. Eleven spillways are listed in Table 1. Two pairs of these, the Ocoee No. 3 - Apalachia set, and the Douglas - Watts Bar set, have crest shapes that are identical within the pair but which were tested for different approach depth (P) values.

The accuracy of the data is evidenced by the plotting of the data points on Figures 2, 3, and 4. Except in some cases at low heads, the deviation of any plotted point from the coefficient curve does not exceed 1/2 percent.

Standard Crests

It has been shown by various authors that the discharge coefficients for all standard crests can be related to each other and that, conversely, the coefficients to be used for a new design can be taken from previous test data.(1), (2), (3), (4) Unfortunately, in most crest designs, due to other design considerations, it is necessary that the shape be varied from the standard form. However, this does not mean that satisfactory coefficients cannot be obtained, as sufficient data are now available on a range of crest shapes. By comparison

TABLE 1

Project	Model Scale	Design Head H_o	Upstream Depth P	$\frac{H_o}{P}$	Pier Nose Radius
Hales Bar	1:34.76	18'	32'	0.56	3.00'
Ocoee No. 3	1:28.72	23'	67'	0.35	3.00'
Apalachia	1:28.72	23'	97'	0.24	3.00'
Fort Patrick Henry	1:50	35'	43'	0.81	3.25'
Wheeler	1:34.35	16.5'	43'	0.38	2.50'
Wilson	1:39.4	19'	75'	0.25	4.00'
Douglas	1:35	23.5'	133'	0.18	3.25'
Watts Bar	1:35	23.5'	52'	0.45	3.25'
Pickwick Landing	1:50	31.5'	32'	0.98	3.75'
Chickamauga	1:50	-	20'	-	4.00'
Guntersville	1:50	-	18'	-	4.00'

of crest shapes, designers may select a coefficient for any particular crest.

Dimensionless plotting provides a means for comparison of crest shapes. This method is used in Figures 5 through 8 on which seven TVA crests which closely approximate standard crests are shown by the solid lines with the dashed line representing a standard crest shape.(1) The horizontal, X, and the vertical, Y, coordinates of the crest curve have been divided by the design head, H_o. The design head was determined by fitting the real and standard curves at the crest point (X = O) and at the intersection of the curve with the upstream vertical face. This design head value is given in Table 1. The design head discharge coefficient (C_o) taken from Figures 2 and 3 is shown on Figures 5 through 8.

The TVA crests all fairly closely approximate the standard curve from the upstream spillway face to a point somewhere downstream from the crest which was determined by the position of the gate seal. Below this latter point, the crest shape was modified to fit the trajectory of a jet issuing from under the gate when set at a small opening. The upstream face for a standard crest is vertical. The upstream face of the TVA crests, as shown on Plates 5 through 8, deviates from the vertical. Other experimenters have established that the shape of the upstream face generally has little influence on the discharge coefficient.(2)

The comparative crests in Figures 5 through 8 have been placed in the order of decreasing design head coefficient (C_o). However, no reasonable correlation of C_o with either upstream shape of $\frac{H_o}{P}$ can be determined.

Figures 5 through 8 indicate that the shape of the curve from the crest to a point somewhere in the neighborhood of $\frac{X}{H_o} = 0.5$ materially affects the coefficient. As the curve is raised above the standard curve, the coefficient is decreased. This can be seen by comparing the $\frac{Y}{H_o}$ values at $\frac{X}{H_o} = 0.5$ with C_o.

The relationships between the discharge coefficient and the ratio of any head to the design head ($\frac{H}{H_o}$) are shown in Figure 9. In Figure 9(a) the value

of C is plotted against $\frac{H}{H_o}$ for the four crests, Apalachia, Ocoee No. 3, Hales Bar, and Fort Patrick Henry, which most closely follow the standard crest shape. The maximum variation of the individual points from the average curve for TVA crests is one-half of one percent. The standard crest curve shown by the dashed line on this figure is from Creager and Justin, Hydro-Electric Handbook.[1] This curve is about 2 percent higher than the TVA curve. Figure 9(b) is a dimensionless plot of the data from Figures 2 and 3. The deviation of the points from the average curve is greater than in Figure 9(a) since all crests are included, but for design purposes the curve should be useful. Actually, the curve is better established than it may appear since the curve itself obliterates a number of the test points.

Irregular Spillway Crests

The designation "irregular spillway crests" is used to differentiate between standard spillway crests and other crest forms. Only two of the TVA spillways, Chickamauga and Guntersville, have irregular spillway crests. Both are trapezoidal in cross-section. Details of these spillway crests and the discharge coefficients calculated by equation (1) from the model study data are shown on Figure 4. The two crests differ chiefly in the shape of the upstream and downstream edges of the crest and the height above the apron. Over the range of the Chickamauga tests the Chickamauga coefficients are consistently from 3 to 5 percent higher than those for Guntersville. The additional height of the crest above the apron and the rounding of the near upstream edge of the Chickamauga crest would operate to increase the discharge coefficients.

Effect of Operating Adjacent Spillway Bays

In TVA's water control operations, it is necessary to operate single spillway bays and groups of consecutive spillway bays. Since a greater contraction forms at a pier situated next to a closed bay, models of the Wilson and Wheeler spillways were tested with adjacent spillway bays open and closed to determine the difference in contraction effects at the piers.

Figure 10 shows the head-coefficient relationships for the two conditions tested. The discharge coefficient at the design head was 5.6 percent higher at Wheeler Dam with adjacent bays opened and 4.4 percent higher at Wilson Dam than with these bays closed. These relationships show the importance of spillway pier contraction effects in spillway discharge determinations.

Submergence Discharge Coefficients for Flow Over Spillway Crests

TVA's Chickamauga, Guntersville, Pickwick Landing, and Watts Bar Dams are subject to submergence of the crest at periods of high discharge. To determine the effect of this submergence, model tests were conducted by setting up a constant rate of discharge and varying the tailwater elevation to determine the relationship between the headwater and tailwater elevations. This procedure was repeated for several discharge rates covering the operating range at the dam.

Two flow conditions were observed in the model tests which are characterized as plunging nappe and flowing nappe. In the condition of plunging nappe the discharge issuing from the spillway plunges down into the tailwater and appears to follow the boundary surface of the spillway. In the flowing nappe the flow is more or less horizontal, producing an undulating surface flow in

the tailrace channel. The plunging nappe generally occurs with low submergence while the flowing nappe occurs with high submergence. When the headwater and tailwater head relationship was plotted for each series of tests, for a constant rate of discharge, it was found that the change from plunging nappe to flowing nappe had no apparent effect on the discharge coefficient.

The results from these tests on the four spillways have been plotted on Figure 11 in the dimensionless form $\frac{d}{H}$ versus $\frac{C_S}{C}$ where d is the depth of submergence and H is the total head above the crest. C_S was calculated from Equation (1) using H for the submerged condition while C was obtained using H for the free flow condition.

For all conditions tested no systematic variation of $\frac{C_S}{C}$ could be determined for any variable except the $\frac{d}{H}$ ratio. No relatively low discharges were tested however since in practice the TVA installations can never be submerged at low discharges.

In Figure 12 the four curves of Figure 11 are shown on a single plot. While the maximum spread between curves is about 10 percent, this is to be expected considering the wide range of crest shapes used in the tests.

Free Discharge Coefficients for Flow Over Vertical Lift Gates

The Pickwick Landing vertical lift gates are representative of this type of gate, which is used on several TVA projects. Figure 13(b) shows details of the lower spillway gate leaf. For heads greater than 2 feet, this gate is essentially a sharp-crested weir 40 feet long and 20 feet high with piers 7.5 feet thick at each end of the gate. Air intakes were installed in the sides of the piers just below the top of the gate to ventilate the underside of the nappe.[7] Model tests were conducted with the 1:50 scale 3-bay spillway model.

Figure 13(a) shows the head-coefficient relationship for flow over the crest of the spillway gate. The coefficient C was calculated from Equation (1) using the top of the gate as crest elevation. The points define the head-coefficient relationship for heads between 3 and 28 feet. Each point was obtained from the average of 3 to 5 separate tests. A constant value of C equal to 3.428 is shown for heads above 12 feet. From 12 feet down to about 4 feet, the model test curve shows a gradual rise in the coefficient with an abrupt drop-off when the heads are approximately 4 feet and less. This curve takes the characteristic form for a sharp-crested weir with the rise and fall in the coefficient curve due to the nappe clinging to the surface of the weir. This phenomenon is a function of the absolute head. Therefore, similarity between the model and prototype did not exist for prototype heads below 12 feet. Since the gate has a 10-inch flat top, at low heads the prototype can be expected to exhibit discharge characteristics similar to those of the model. However, above a head of about 2 feet the prototype can be expected to act similarly to a sharp-crested weir and to have a flat coefficient curve.

Submergence Discharge Coefficients for Flow Over A Vertical Lift Gate

To obtain data on the effect of the submergence of flow over vertical lift gates, model tests were conducted in a manner similar to that used in determining submergence effects on spillway crests. The coefficient C_S was calculated from Equation (1) in a manner similar to that used for the spillway crest data but using the top of gate as the crest elevation. Figure 14 shows

a plot of the headwater-tailwater relationships obtained. These curves illustrate the characteristic flow phenomena obtained with this type of gate. Each constant discharge curve begins with a horizontal line where the head-discharge relationship is not affected by the tailwater level. Just before the tailwater elevation reaches the gate crest level, there is a drop in the headwater level for an increase in the tailwater level. Observations of the model operation showed that at this point the air vents, located in the sides of the piers just below the crest of the spillway gate, became submerged by the tailwater, reducing the contraction of the lower nappe issuing from the gate crest. The discharge over the gate was thus increased with a consequent lowering of the headwater level.

The plunging nappe and flowing nappe flow conditions, previously described, also occurred in this type of flow. In this case the change from one to the other is apparent in the data. The dashed line on Figure 14 indicates the approximate location of the change. At these points the curves show a definite discontinuity in shape. The data of Figure 14 can be reduced in coefficient form to the single curve representation shown in Figure 15. In this figure, the ratio of coefficient of submergence to the free discharge coefficient is related to the ratio of depth of submergence to total head above the crest of the gate. A constant value of C, equal to 3.428, was used in calculating the ratio of $\frac{C_s}{C}$.

Discharge Coefficients for Flow Under Tainter Gates

The flow under Tainter gates mounted on curved crests is controlled by the geometry of three interrelated variables—the crest shape, the gate, and the gate setting. The major factors which influence the discharge relationships are the position of the gate seal point with respect to the highest point of the spillway crest and the curvature of the upstream face of the gate. In obtaining the model data on TVA's various Tainter gate installations no attempt has been made to determine the quantitative effect of these factors individually. The data presented in Figures 16 and 17 for the Wheeler, Apalachia, Watts Bar, and Hales Bar settings are not, therefore, applicable to other installations unless the several variables involved are similar.

Data on Tainter gate coefficients previously published have, in most cases, been based on flow along a horizontal surface although many installations of these gates are made on curved crests. The tests reported here are for Tainter gates mounted on curved spillway crests where the pressure distribution differs considerably from that in a horizontal channel. The coefficients obtained from tests on a horizontal channel do not apply to installations on curved crests.

The discharge coefficients for Figures 16 and 17 were calculated by Equation (2) with the heads measured above the crest elevation. The curves designated "Gates raised above water surface" are the free discharge curves taken from Figures 2 and 3, for which C values were calculated by Equation (1). The points connected by the dashed lines represent the point at which the water just touched the bottom edge of the gate. The difference in the C values is, of course, due to the use of Equation (2) for the gate curve. The Hales Bar tests were not run in a manner that allowed the determination of the point of contact of the gate with the free water surface.

The gate opening was measured as the vertical distance above the crest. This definition leads to the somewhat peculiar variation in the coefficients for small gate openings. In Figure 16(a) the data for Wheeler Dam are presented.

The Wheeler gate was positioned, as shown in the insert, with the seal at the high point on the crest. With this design, except at the smallest opening, the coefficient curves for each gate position followed the general pattern of an increase in C for an increase in gate opening. In Figure 16(b) the data for Apalachia Dam show that when the gate seal is located 3.99 feet downstream and 0.50 foot below the highest point on the crest, the coefficients for gate openings of less than 6.45 feet increase materially with a decrease in gate opening. This is caused by an arbitrary use in Equation (2) of H as measured above the crest rather than as measured above the elevation of the spillway surface below the gate. Thus, while H is always too small, at the smaller gate openings the effect becomes more appreciable and results in the increase in C.

Tainter Gate Discharge Coefficients with Adjacent Gates Opened or Closed

The results of tests on the 6-spillway bay model of Wheeler Dam with one gate and with six gates in operation are shown in Figure 18. In operating with all six gates the contraction effect of the end piers was the same as for the intermediate piers since the model was constructed with half piers against the sidewalls of the flume. This operation thus represented all adjacent bays open.

Effect of Model Scale on Free Discharge Coefficients

In developing discharge ratings for prototype structures from model data it is important that the scale at which the model is built be such that the coefficients determined be applicable to the prototype structure. One author has presented data to indicate that with an increase in the model size the discharge coefficients increase.[5] To study this relationship, a series of precise tests was made at TVA's Hydraulic Laboratory under the joint sponsorship of the American Society for Engineering Education, the University of Tennessee, and TVA.[6] In this study three models of Pickwick Landing spillway were constructed to scales of 1:50, 1:100, and 1:200. Each model consisted of a reproduction of three spillway bays. The shapes of the spillway crest and piers are shown in Figure 3. Similar techniques were used in all tests with one exception. Hook gages reading to 0.0001 foot were used for the 1:200 scale tests and gates reading to 0.001 foot were used in the 1:50 and 1:100 tests.

Discharge coefficients for free flow over the crest of each model are shown in Figures 19(a), (b), and (c). The coefficients of discharge were calculated using Equation (1). Each curve was drawn through the average of the plotted points.

A comparison of the three coefficient curves is shown in Figure 19(d). The maximum spread of the curves does not exceed 2 percent. For prototype heads between 2 and 8 feet the three coefficient curves are practically identical. At 13 feet the 1:100 scale model coefficient curve is approximately 1 percent lower than the 1:50 and 1:200 scale model curves. At 43 feet the 1:100 curve is 1 percent higher than the 1:50 data and the 1:200 is 1 percent lower than the 1:50. Since there is no consistent relationship between the coefficient curves, it is logical to conclude that these variations are simply the result of experimental error and that the model scale did not affect the stage coefficient relationship. The close agreement of the coefficient curves at the three scales supports the preparation of prototype ratings based on model tests.

ACKNOWLEDGMENTS

The model studies were made under the general direction of Albert S. Fry, Chief, Hydraulic Data Branch, TVA, M. ASCE, and under the immediate supervision of Dr. G. H. Hickox, M. ASCE, former Head of the TVA Hydraulic Laboratory, and Rex A. Elder, M. ASCE, Head, TVA Hydraulic Laboratory. The work has been carried on over a number of years, and personnel too numerous to mention have participated in the conduct of the model tests. The assistance of Jack C. Jones, Jr. M. ASCE, is acknowledged in making the calculations and preparing the figures in this paper. The writer also acknowledges the many helpful suggestions made by Dr. Hickox and Mr. Elder.

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Definition of Symbols

Q = Total discharge in cubic feet per second.
L = Spillway crest length in feet.
H = Total head above crest, including velocity head of approach, in feet.*
h = Velocity head of approach $\frac{v^2}{2g}$ in feet.*
d = Submergence tailwater, measured above crest, in feet.*
g = Acceleration of gravity in feet per second
v = Average velocity of approach in feet per second.
D = Depth of flow above crest in feet.*
D_1 = Depth, bottom of gate to water surface, in feet.+
C = Coefficient of discharge for any head.
C_0 = Coefficient of discharge for design head.
C_s = Coefficient of discharge for submerged flow.
H_0 = Design head for standard crest, including velocity head of approach, in feet.
P = Depth of approach channel, crest to river bed, in feet.*
X,Y = Crest coordinates in feet.

*See Figure 1(a).
+See Figure 1(b).

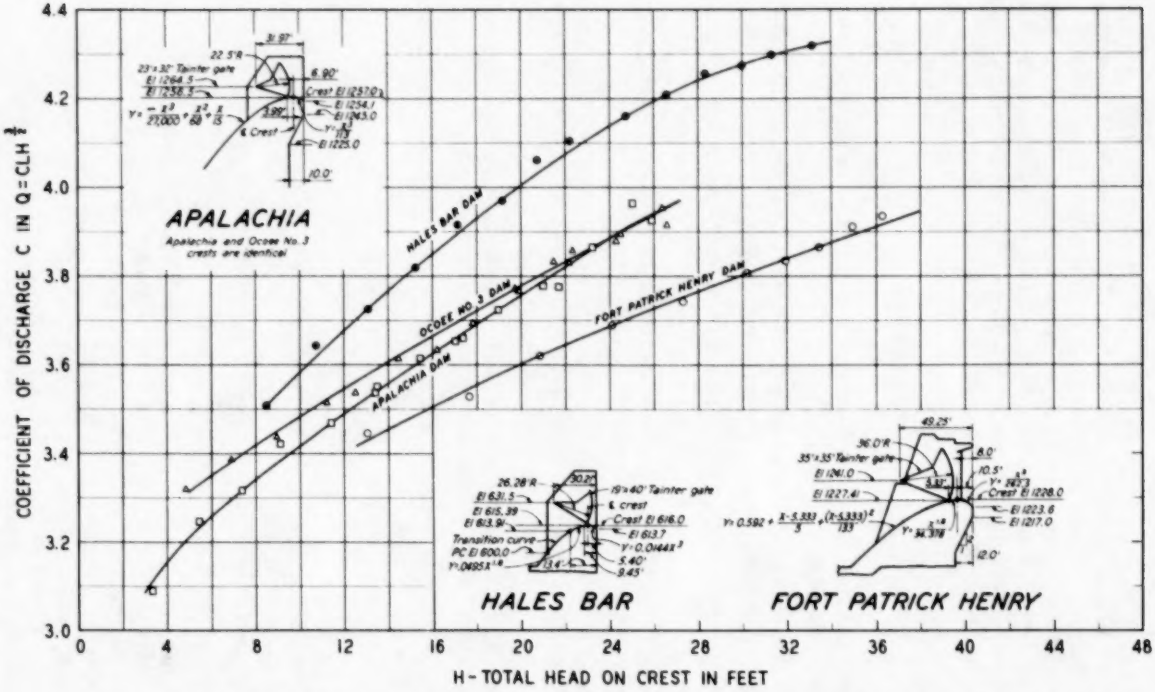

FIG. 2 - DISCHARGE COEFFICIENTS FOR FREE FLOW OVER STANDARD SPILLWAY CRESTS

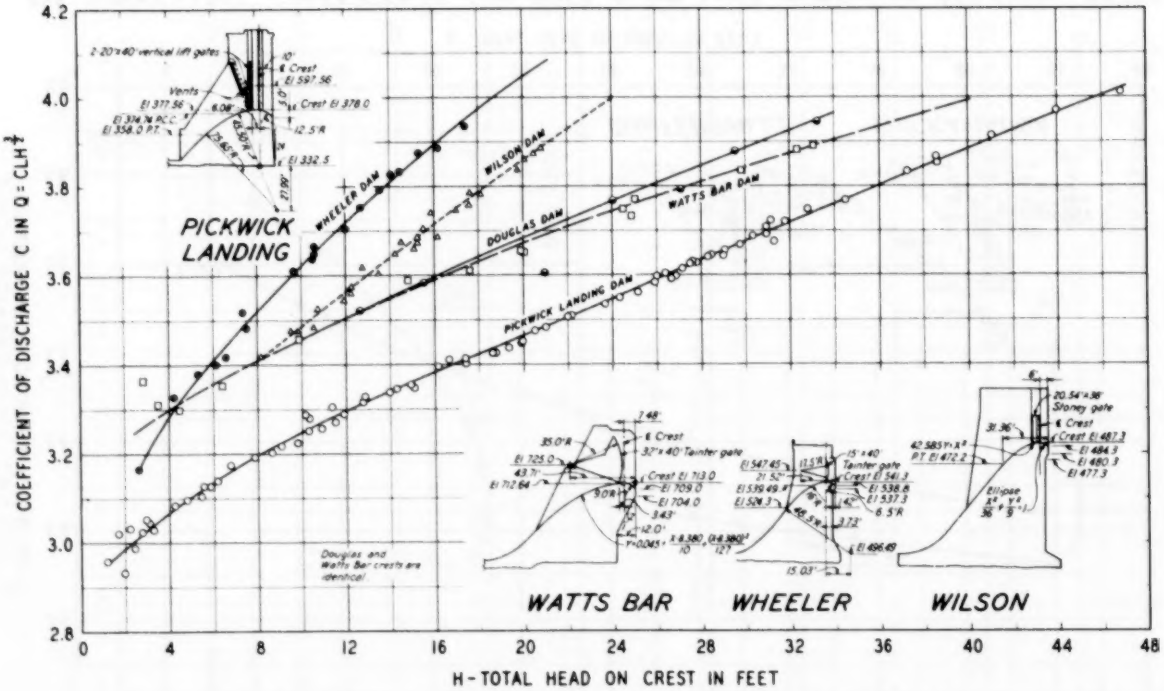

FIG. 3 - DISCHARGE COEFFICIENTS FOR FREE FLOW OVER STANDARD SPILLWAY CRESTS

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+See Figure 1(b).

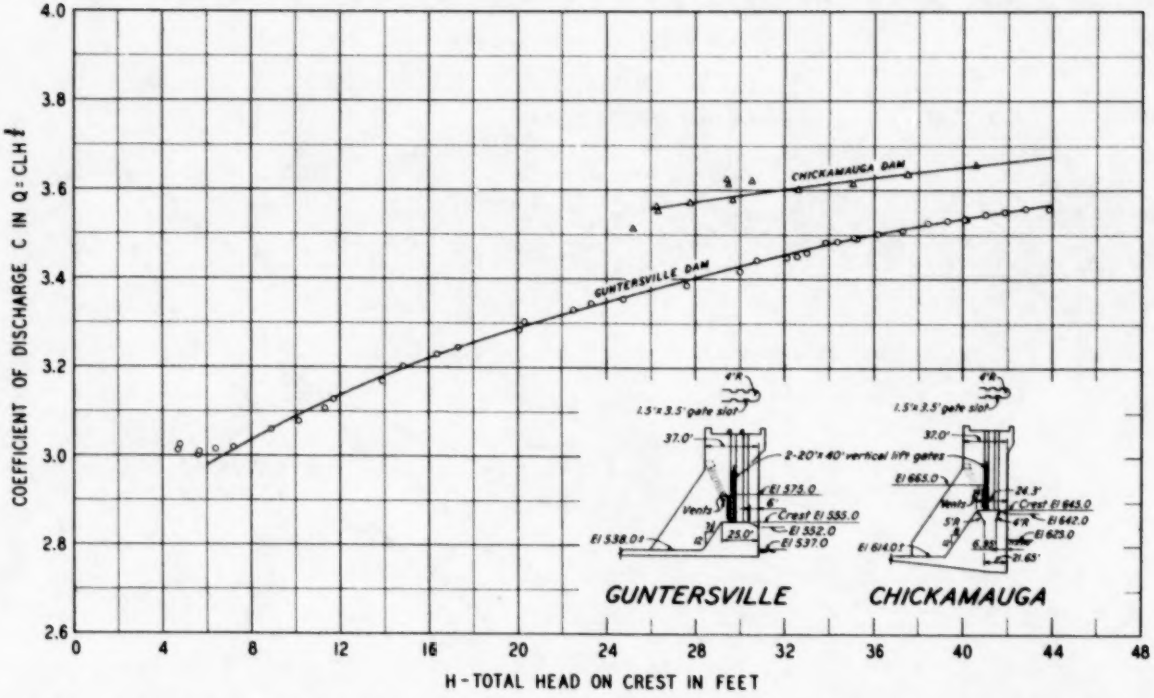


FIG. 4-DISCHARGE COEFFICIENTS FOR FREE FLOW OVER IRREGULAR SPILLWAY CRESTS

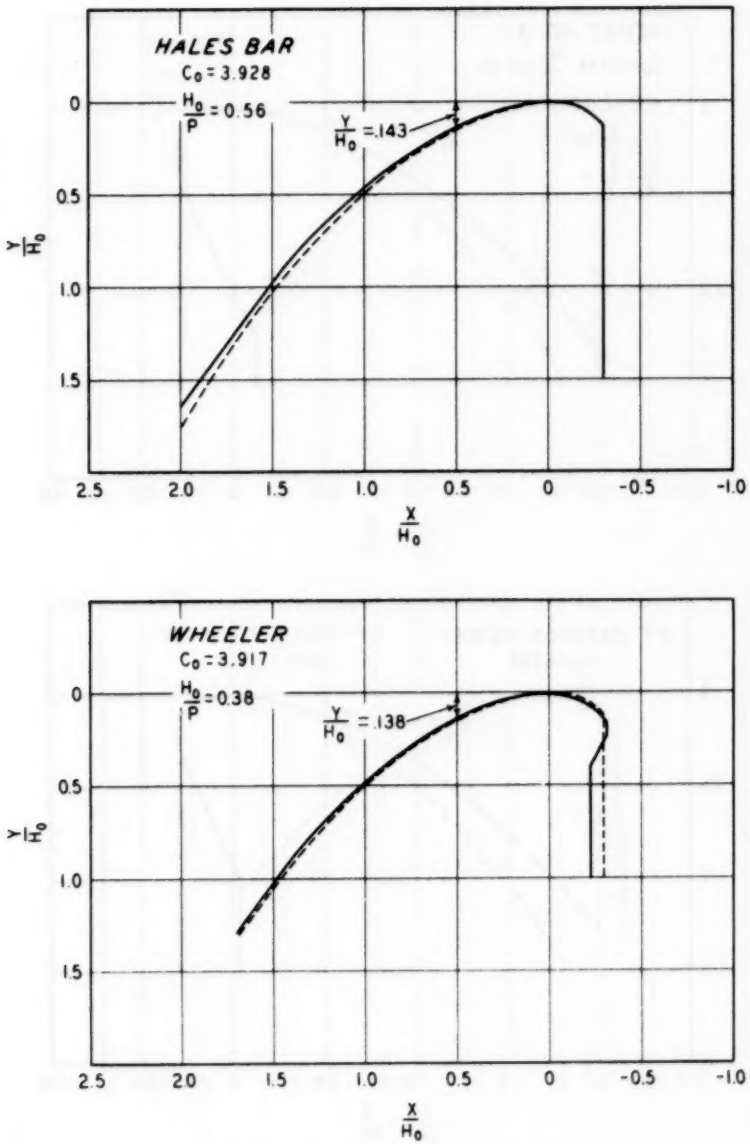
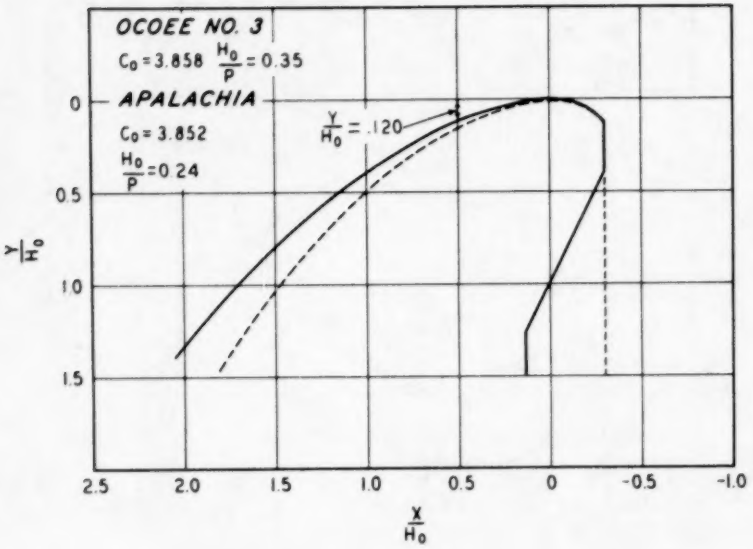


FIG. 5 - COMPARATIVE CRESTS



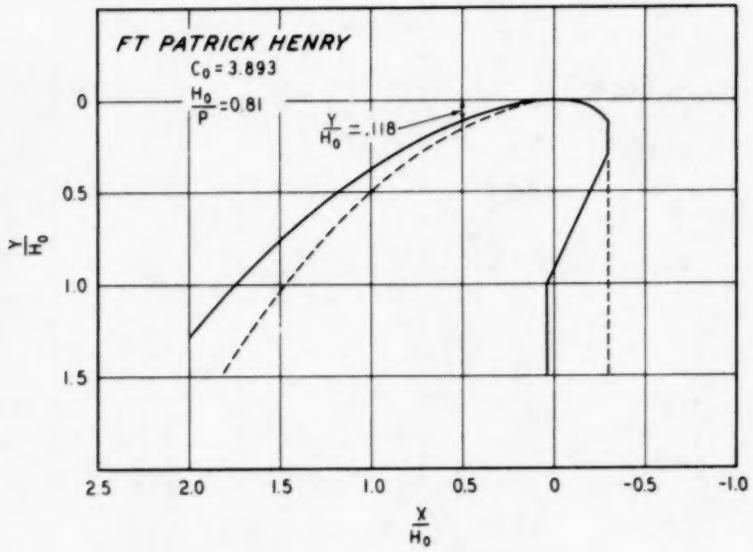


FIG. 6-COMPARATIVE CRESTS

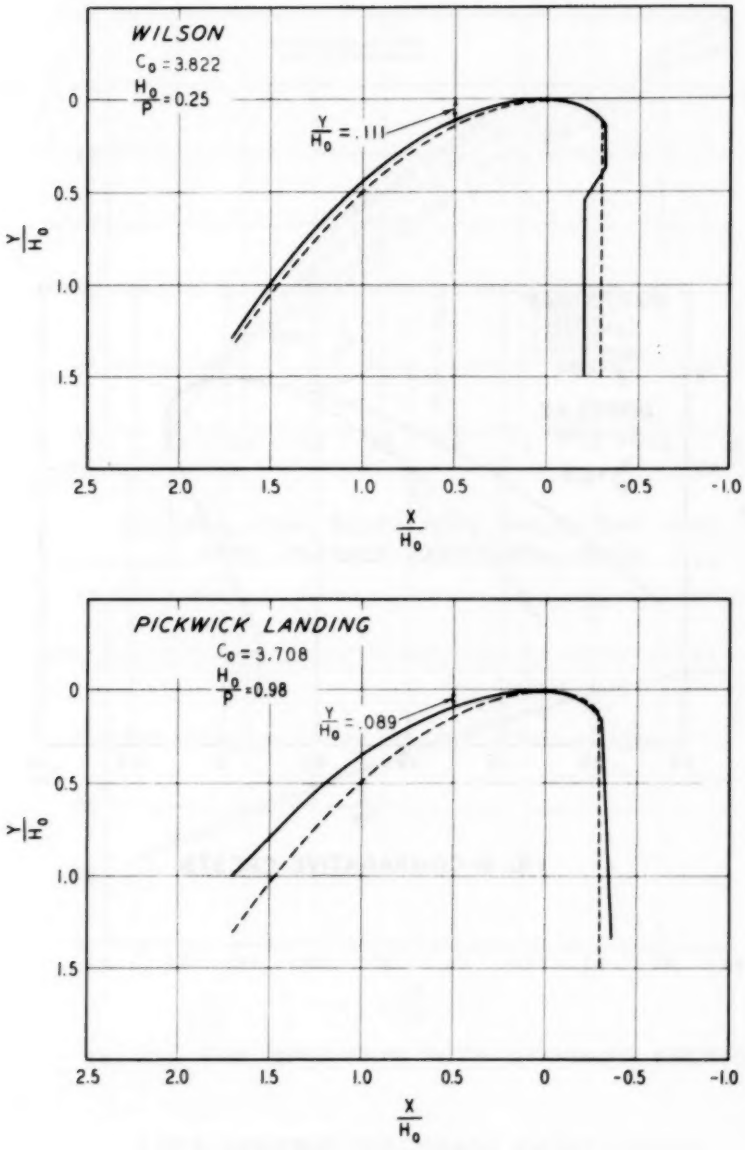


FIG. 7 - COMPARATIVE CRESTS

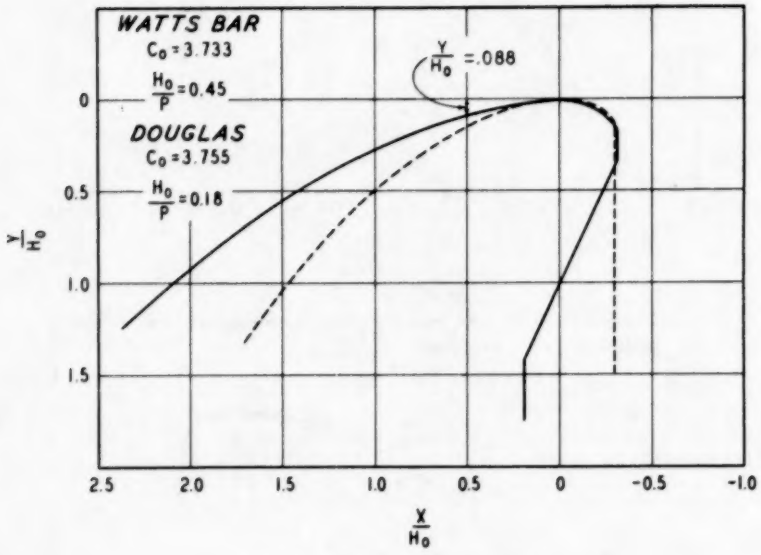
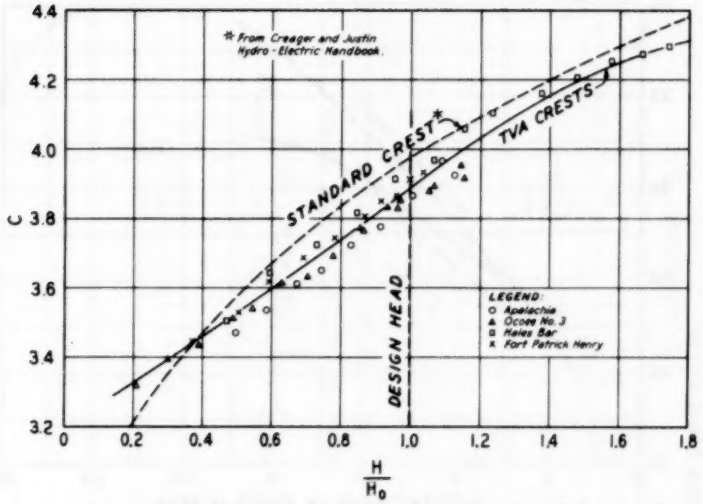
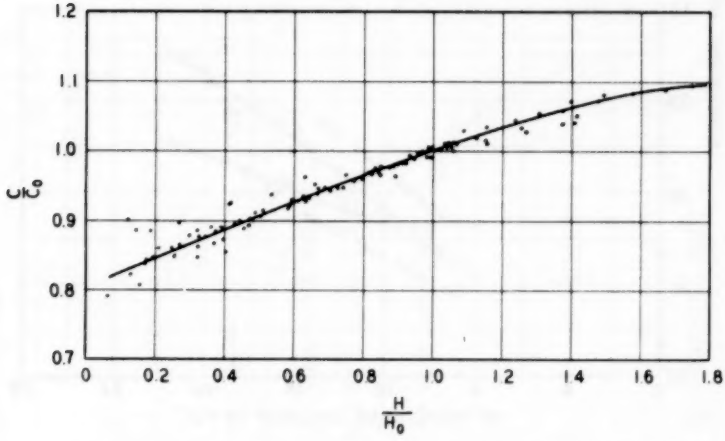


FIG. 8- COMPARATIVE CRESTS

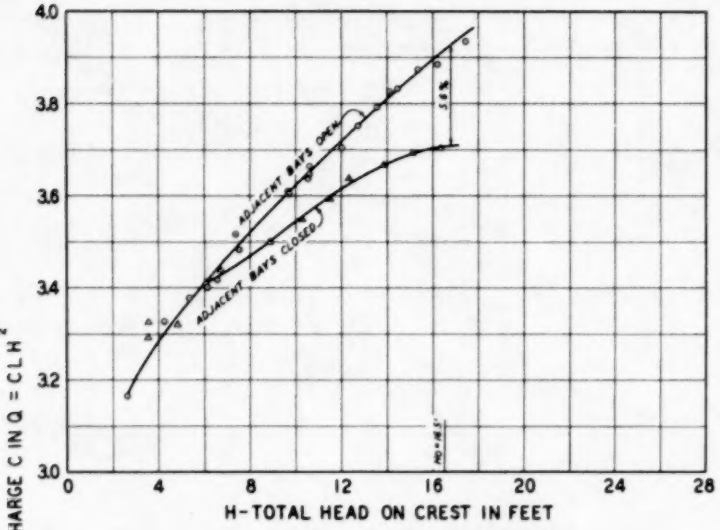


(a) APALACHIA, OCOEE NO. 3, HALES BAR AND FORT PATRICK HENRY SPILLWAYS

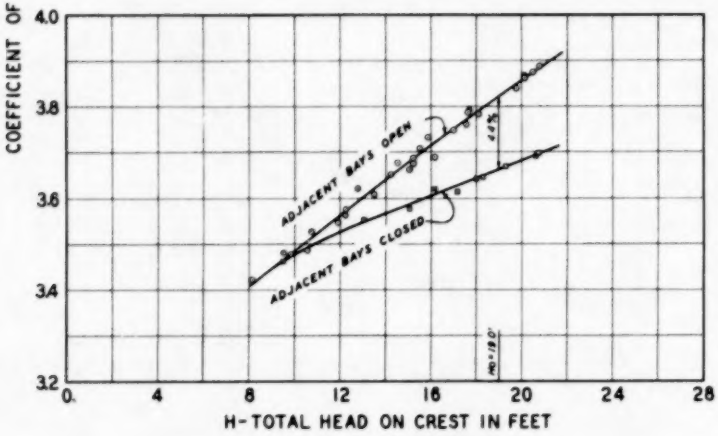


(b) ALL TVA SPILLWAYS WITH STANDARD CRESTS

FIG. 9-SPILLWAY DISCHARGE COEFFICIENTS FOR STANDARD CRESTS



(a) WHEELER DAM



(b) WILSON DAM

FIG. 10-EFFECT OF ADJACENT SPILLWAY BAY OPERATION

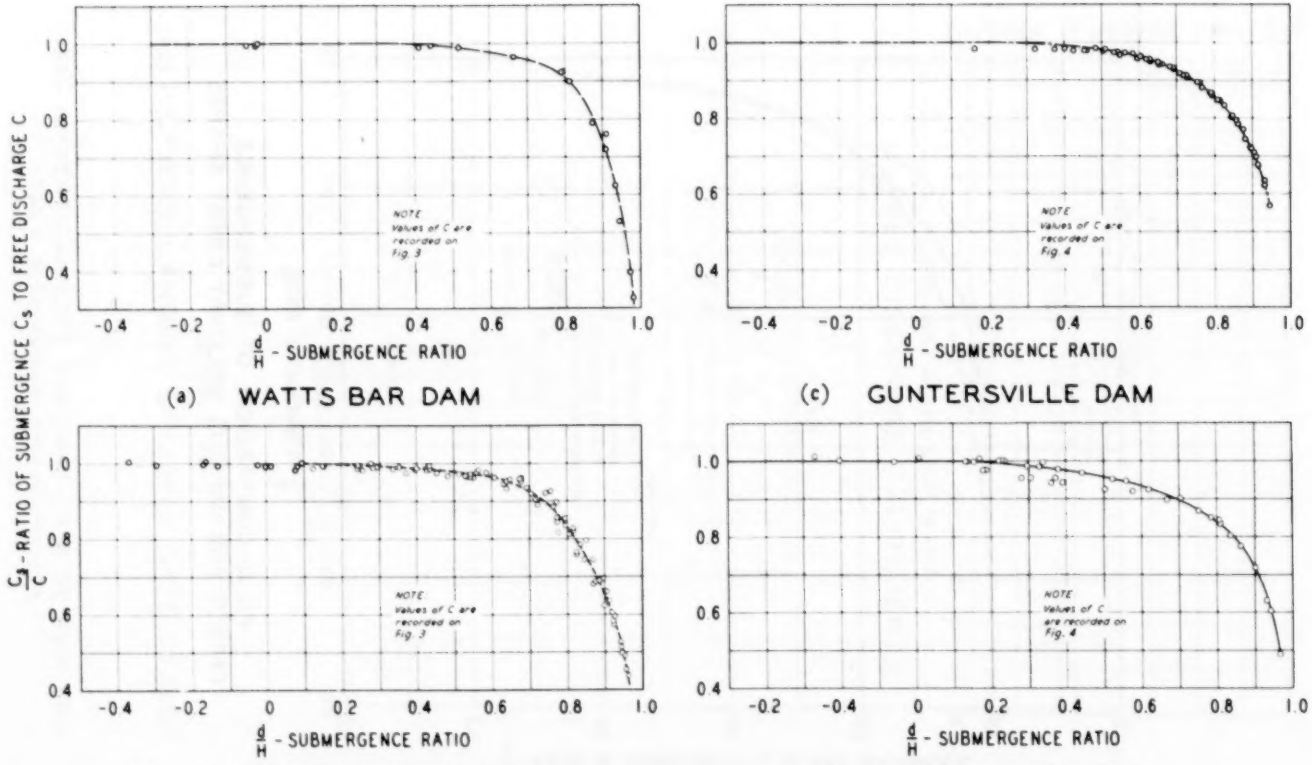

$\frac{C_s}{C}$ - RATIO OF SUBMERGENCE C_s TO FREE DISCHARGE C
$\frac{d}{H}$ - SUBMERGENCE RATIO
NOTE
Values of C are recorded on Fig. 3
Values of C are recorded on Fig. 4
(a) WATTS BAR DAM
(b) PICKWICK LANDING DAM
(c) GUNTERSVILLE DAM
(d) CHICKAMAUGA DAM

FIG. 11-EFFECT OF SUBMERGENCE ON DISCHARGE COEFFICIENTS

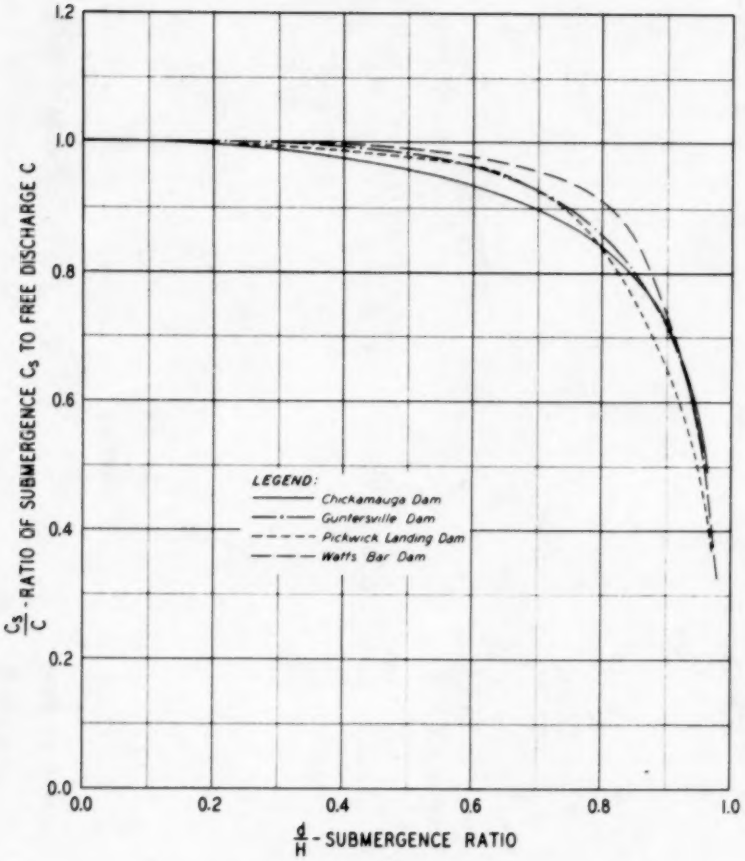
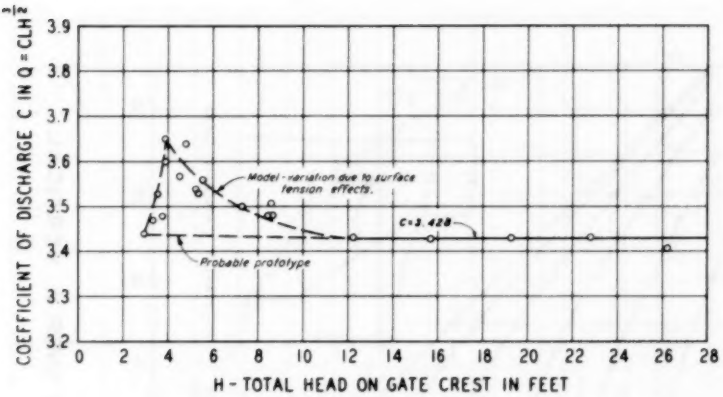
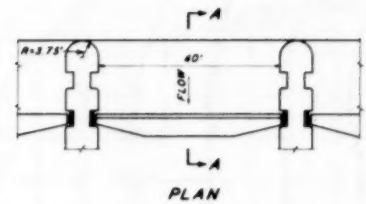
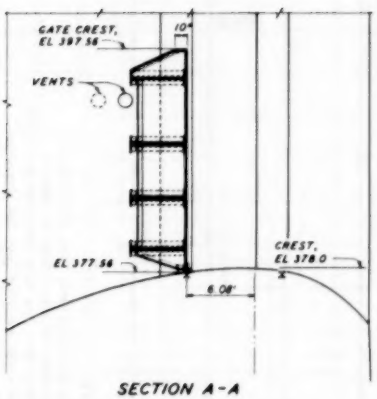


FIG. 12-COMPARISON OF SUBMERGENCE EFFECT FOR VARIOUS SPILLWAY CREST SHAPES



(a) FREE DISCHARGE COEFFICIENTS





(b) PICKWICK LANDING SPILLWAY GATE DESIGN

FIG. 13-VERTICAL LIFT SPILLWAY GATE DESIGN AND FREE DISCHARGE COEFFICIENTS

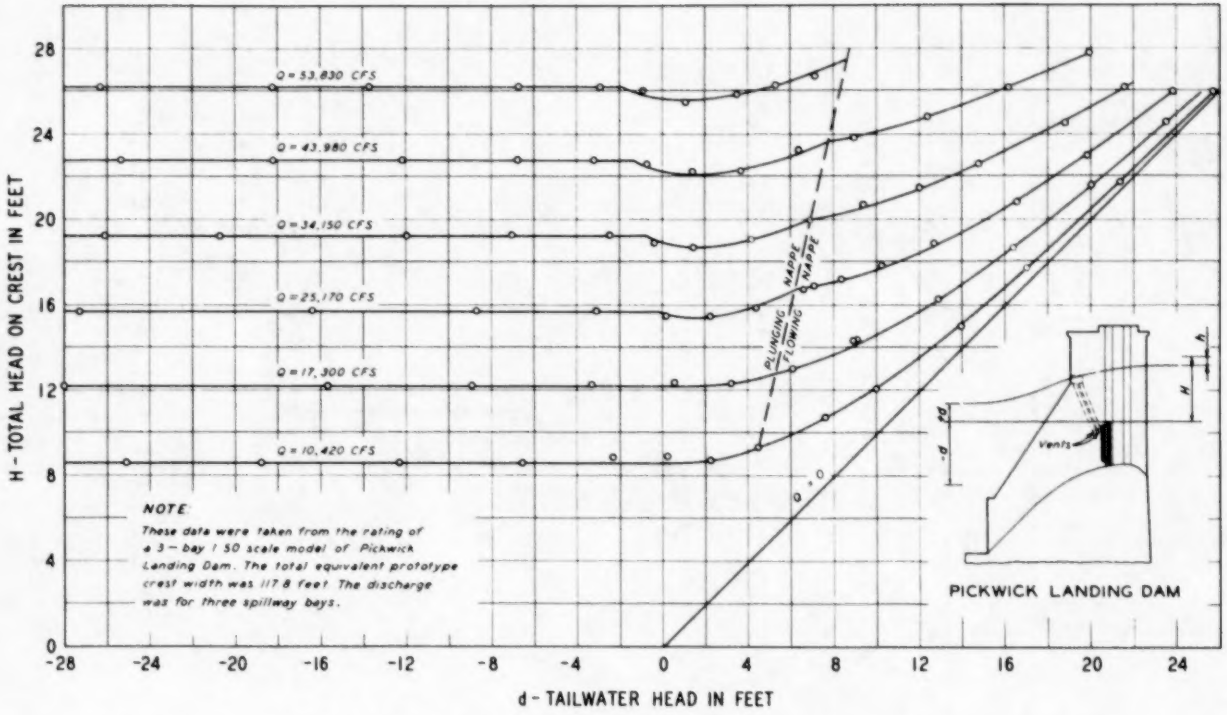

H - TOTAL HEAD ON CREST IN FEET
d - TAILWATER HEAD IN FEET
Q = 53,830 CFS
Q = 43,980 CFS
Q = 34,150 CFS
Q = 25,170 CFS
Q = 17,300 CFS
Q = 10,420 CFS
Q = 0
NAPPE PLUNGING
NAPPE FLOWING
NOTE
These data were taken from the rating of a 3 - bay 1:50 scale model of Pickwick Landing Dam. The total equivalent prototype crest width was 117.8 feet. The discharge was for three spillway bays.
Vents
PICKWICK LANDING DAM

FIG. 14 - HEADWATER - TAILWATER RELATION CURVES FOR FLOW OVER A VERTICAL LIFT SPILLWAY GATE

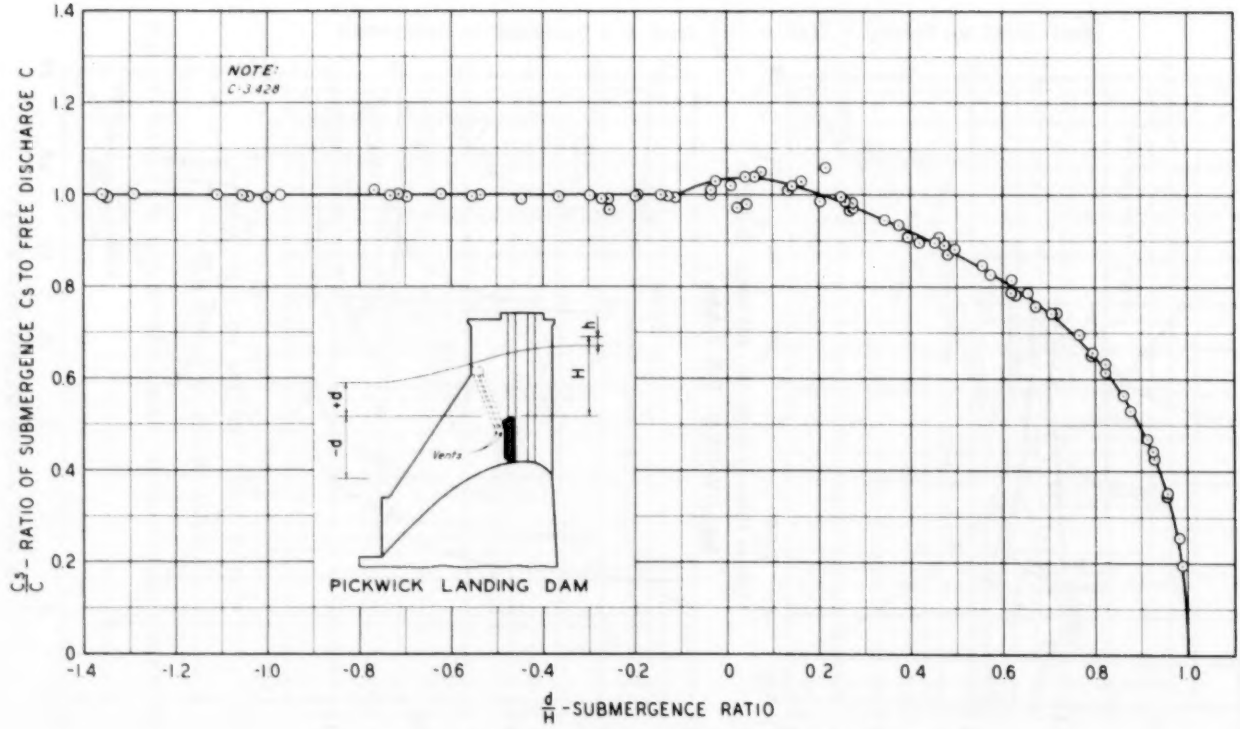
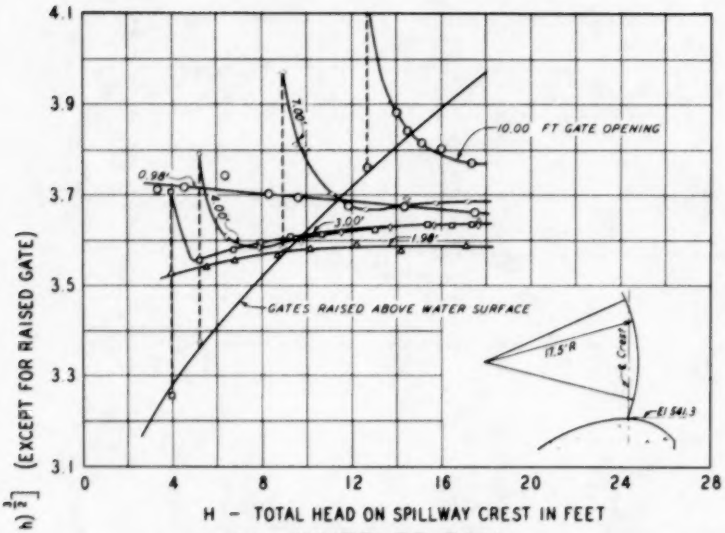
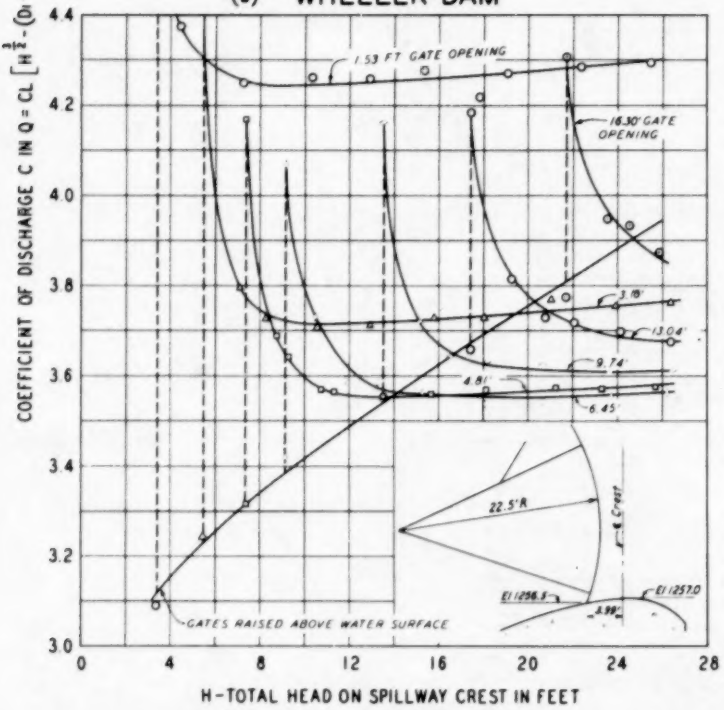


FIG. 15-SUBMERGENCE EFFECT FOR FLOW OVER A VERTICAL LIFT SPILLWAY GATE

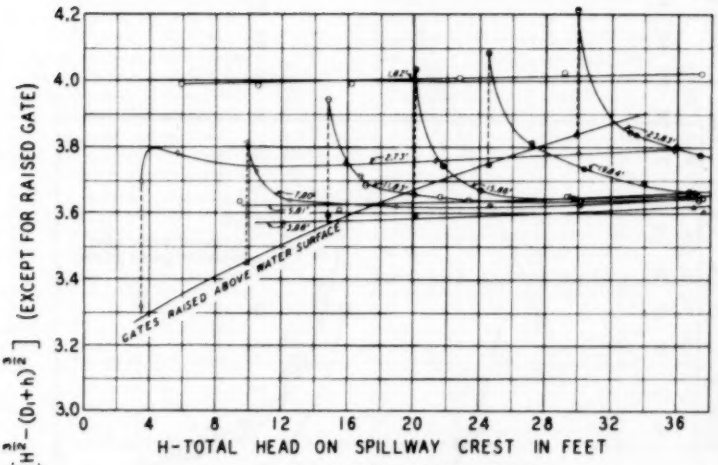


(a) WHEELER DAM

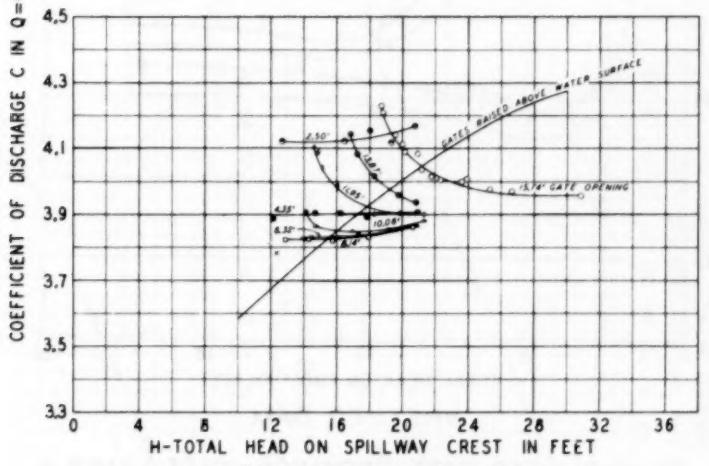


(b) APALACHIA DAM

FIG. 16 - TAINTER GATE SPILLWAY DISCHARGE COEFFICIENTS

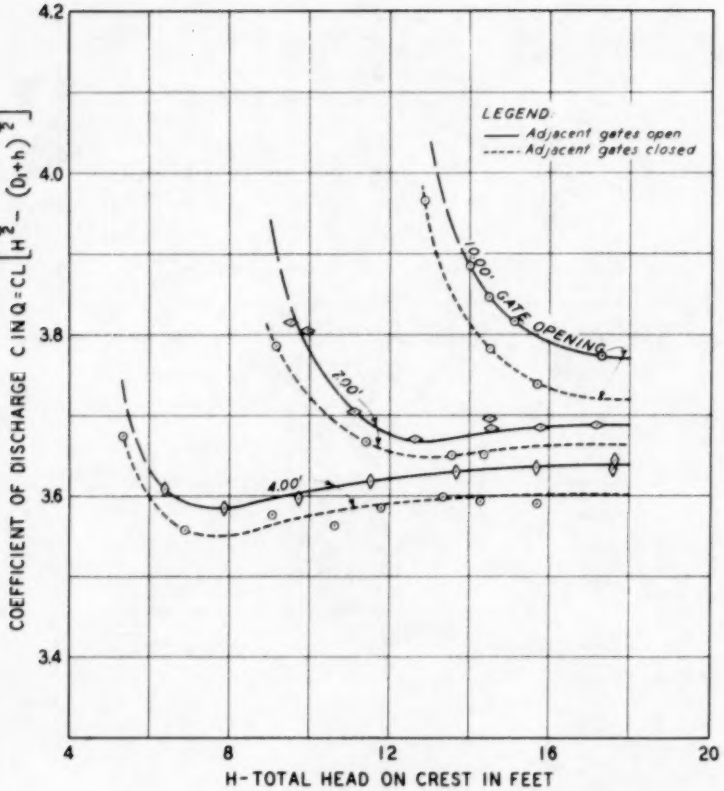


(a) WATTS BAR DAM



(b) HALES BAR DAM

FIG. 17 - TAINTER GATE SPILLWAY DISCHARGE COEFFICIENTS



WHEELER DAM

FIG.18-TAINTER GATE DISCHARGE COEFFICIENTS C WITH ADJACENT GATES OPENED OR CLOSED

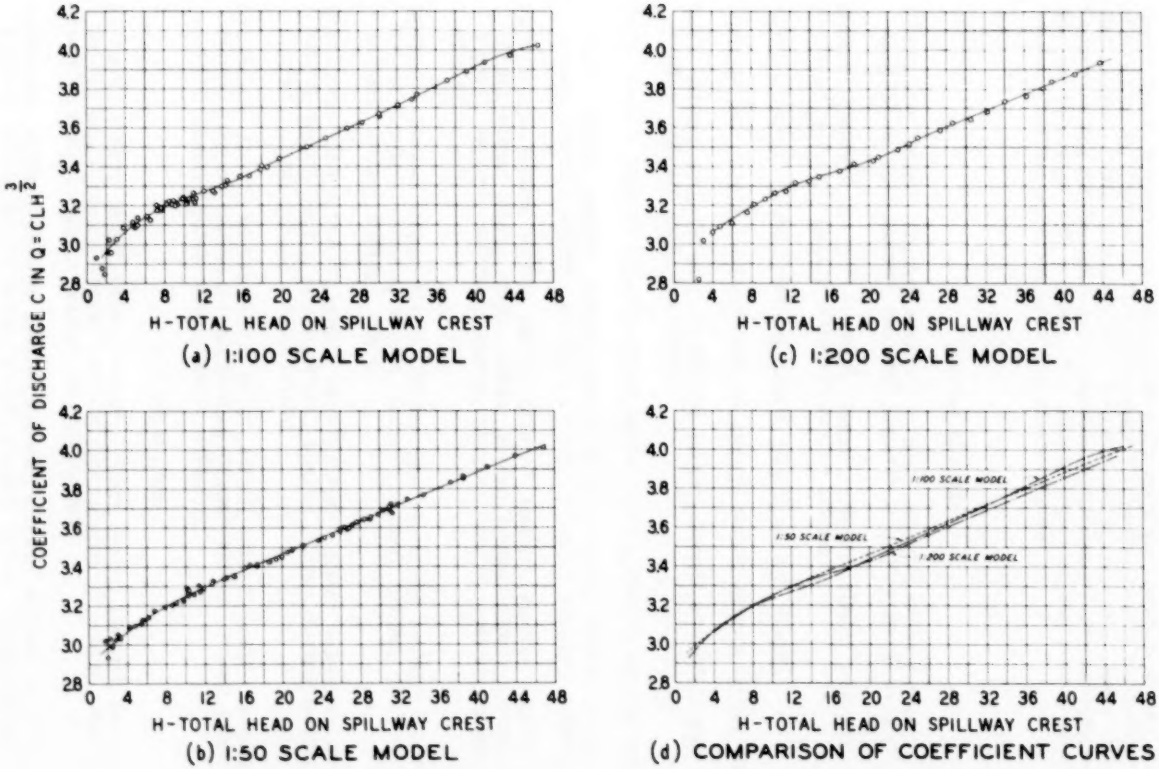


FIG. 19-EFFECT OF MODEL SCALE ON DISCHARGE COEFFICIENTS FOR FLOW OVER PICKWICK LANDING SPILLWAY CREST

PROCEEDINGS-SEPARATES

The technical papers published in the past year are presented below. Technical-division sponsorship is indicated by an abbreviation at the end of each Separate Number, the symbols referring to: Air Transport (AT), City Planning (CP), Construction (CO), Engineering Mechanics (EM), Highway (HW), Hydraulics (HY), Irrigation and Drainage (IR), Power (PO), Sanitary Engineering (SA), Soil Mechanics and Foundations (SM), Structural (ST), Surveying and Mapping (SU), and Waterways (WW) divisions. For titles and order coupons, refer to the appropriate issue of "Civil Engineering" or write for a cumulative price list.

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MARCH: 414(WW)[d], 415(ST)[d], 416(SM)[d], 417(SM)[d], 418(AT)[d], 419(SA)[d], 420(SA)[d], 421(AT)[d], 422(SA)[d], 423(CP)[d], 424(AT)[d], 425(SM)[d], 426(IR)[d], 427(WW)[d].

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NOVEMBER: 534(HY), 535(HY), 536(HY), 537(HY), 538(HY)[c], 539(ST), 540(ST), 541(ST), 542(ST), 543(ST), 544(ST), 545(SA), 546(SA), 547(SA), 548(SM), 549(SM), 550(SM), 551(SM), 552(SA), 553(SM)[c], 554(SA), 555(SA), 556(SA), 557(SA).

DECEMBER: 558(ST), 559(ST), 560(ST), 561(ST), 562(ST), 563(ST)[c], 564(HY), 565(HY), 566(HY), 567(HY), 568(HY)[c], 569(SM), 570(SM), 571(SM), 572(SM)[c], 573(SM)[c], 574(SU), 575(SU), 576(SU), 577(SU), 578(HY), 579(ST), 580(SU), 581(SU), 582(Index).

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c. Discussion of several papers, grouped by Divisions.
d. Presented at the Atlanta (Ga.) Convention of the Society in February, 1954.
e. Presented at the Atlantic City (N.J.) Convention in June, 1954.

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